NBS TECHNICAL NOTE 836

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Detector Actuated Automatic Sprinkler Systems— A Preliminary Evaluation

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DETECTOR ACTUATED AUTOMATIC SPRINKLER SYSTEM - A PRELIMINARY EVALUATION

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An investigation was conducted to evaluate the capabilities of a detector actuated automatic sprinkler system to protect individuals who are intimately associated with the first materials ignited such as bedding materials. Tests were conducted in a simulated nursing home bedroom. System response was evaluated for both smoldering and open flaming ignition sources. It was determined that barring electrical or mechanical failure the system could be nearly 100 percent effective with smoldering fires. The effectiveness with open flaming fires was difficult to evaluate. Although these fires were extinguished with minimum damage in times as short as 36 seconds the possible effects of flammable blankets and sleepwear were not tested. It was estimated that perhaps one third of the potential victims of open flaming fires might be saved. Although these tests were limited in scope, some tentative design criteria for detector actuated sprinkler systems are presented and possible alternatives offered.

Key words: Bedding fires; design criteria; detector actuated automatic sprinklers; detectors; levels of protection; life safety; sprinklers.

1. INTRODUCTION

In the last few years the United States has experienced an increasing number of fires in nursing home occupancies involving injuries and loss of life. This has given rise to considerable interest at both the Federal and local levels in improving the fire protection for these occupancies. In order to define the extent to which fire protection systems can provide life safety, three levels of protection have been proposed [1]. Level 1 would protect the occupant of a room when intimately associated with the fire at its point of origin. This would include patients involved in bedding or clothing fires and would require rapid detection and suppression capabilities in order to save the life. Level 2 protection would safeguard other occupants of the room who might be in danger as the fire begins to spread beyond the first objects ignited. Level 3 Protection would be directed towards confining the fire to the room of origin such that other occupants in the building would not be endangered. Level 3 protection assumes that the maximum loss of life sustained from a fire would consist of the occupants of the room of origin. The analysis which follows is based on state-of-the-art fire protection engineering practice and a series of full-scale fire tests using commercially available equipment to evaluate the possibility of providing Level 1 protection in a simulated nursing home bedroom.

Although a complete automatic sprinkler system can be effective in confining a fire to its room of origin, data obtained in a 35-month period by the Oregon State Fire Marshal's office [2] showed that of

13 fatalities covered by the survey, nine took place in fully sprinklered buildings. In two instances the fires were extinguished by the sprinkler heads. In one case, however, the patient died and in the second case the patient sustained serious burns and was removed by nursing home personnel prior to the operation of the sprinkler head. There was no sprinkler operation in the other 7 cases. In evaluating the circumstances surrounding the 13 fatalities, it was determined that in 11 cases open flames from either matches or cigarette lighters were responsible for the ignition. In one case the time between ignition and discovery was estimated to be less than 5 minutes and it is possible that this fire may also have been the result of an open flame ignition. The last case was definitely of smoldering origin.

Data obtained from the Flammable Fabrics Accident Case and Testing System (FFACTS) maintained by the Office of Information and Hazard Analysis at the National Bureau of Standards indicate that approximately 55% of the bedding fires contained in the data base were initiated by open flame ignition sources. Although FFACTS is not a statistical data base, it contains over 3,000 cases and can provide an indication of trends. Thus it would appear that in order to provide Level 1 protection, a fire suppression system must be capable of responding quickly with detection and suppression capabilities to rapidly developing fires from open flame ignition sources.

2. PURPOSE

The purpose of this test series was to evaluate the effectiveness of a combination detection-suppression system in providing both early warning and suppression capabilities when exposed to fires initiated in bedding by both smoldering and flaming ignition sources. In addition to system effectiveness, the problem of false alarms presently associated with existing smoke detection hardware was also considered. Finally an attempt has been made to provide tentative design requirements, based on engineering judgement and the data available from these tests for the use of detector-actuated, automatic sprinkler systems in nursing homes and care-type facilities.

3. DESCRIPTION OF TEST SYSTEM

The system evaluated by these tests consists of a smoke detector connected to a thermal actuating device. This device is attached to an ordinary sprinkler head. Upon detection of smoke, the thermal actuating device is fired heating and releasing the operating elements of the sprinkler head. Water is then discharged on the fire. The time required from detection to operation of a standard 135°F sprinkler head ranges from 3 to 5 seconds.

3.1 Detectors

Two different types of smoke detectors were used in this test series. One operated on the ionization principle and the other on a light scattering principle. Work presently in progress at the National Bureau of

Standards indicates that the housing surrounding the operating elements of the smoke detector can have a considerable effect on the ability of that detector to respond to slowly moving smoke. Candidate detectors were evaluated by placing them in a test box and exposing them to smoke laden air at velocities of 15, 30, 50 and 100 feet per minute (7.6, 15.2, 25.4 and 50.8 cm sec^{-1}). The rate of smoke development in the box, in terms of light obscuration, was approximately 1 percent per foot per minute (0.014 $ODm^{-1}min^{-1}$).(1) Both detectors used in this test series have good response characteristics when exposed to slowly moving smoke. The velocity profiles for these units are shown in Figure 1. The detectors were tested before and after the fire tests and no changes in velocity profiles were noted.

3.2 Sprinkler Actuation Device

The commercially secured thermal actuating devices consisted of a small metal cylinder containing a solid fuel and an igniter wire. These devices are mounted directly on the sprinkler head. The flame discharge end of the actuating device is oriented such that the flame will impinge on the operating elements of the sprinkler head. The thermal actuators were fired using a smoke detector as a switch to energize the ignitor wire from an appropriate power supply. One actuator tested is currently available and the other is a prototype not yet on the market.

3.3 Sprinkler System

The automatic sprinkler system used for these tests was designed to provide a discharge density of 0.1 gallons per minute per square foot as required by the National Fire Protection Association Standard 13 [3] for Light Hazard Occupancies. Standard pendant heads of ordinary temperature classification (135°F [57°C]) were used throughout all test of the system. Figure 2 shows the arrangement of the system components.

3.4 Reliability of Test System Components

Although single samples of each detector were used, these devices have been tested and approved by recognized testing laboratories according to standard test methods [4,5]. In the testing procedures, many samples of each item are evaluated under normal and adverse conditions. The units used are stock items and are presently available commercially. In addition, each detector was checked at NBS before and after use in the tests and found to operate within the acceptable tolerances. All detectors regardless of manufacturer are subjected to the same tests prior to approval.

All automatic sprinkler heads unless indicated as prototypes have been listed by Underwriters' Laboratories [6] and their reliability is not in question.

The actuating devices have not as yet received approval but have been submitted to Underwriters' Laboratories for listing. Samples of these devices were bench tested prior to use in these tests and were

(1) ODm^{-1} = optical density per metre.

found to operate as designed. No design failures were observed during the full-scale tests.

4. TEST PROGRAM

4.1 Description of Test Room

The tests were conducted in a 10 foot square (3.05 m) test room with a 9 foot (2.7 m) ceiling. The test room was of noncombustible construction. A plan view of the test room showing the location of the automatic sprinkler head, the detector, and the bed is given in Figure 3.

4.2 Instrumentation

Temperatures in the room and in the bedding material and smoke levels in the room were recorded throughout each test. Temperatures were recorded using 24 gage chromel-alumel thermocouples. Room temperatures were measured with thermocouples located at the ceiling adjacent to the sprinkler head and at the 5 foot (1.5 m) level adjacent to the bed. An array of seven thermocouples was placed on the bed in the area of ignition in order to determine the area burned and the temperatures to which a patient might have been exposed had the bed been occupied at the time of the fire (see Figure 4). Smoke levels were recorded during the test using 1.5 foot (0.46 m) projected beam smoke meters. One smoke meter was located at the ceiling adjacent to the detector to measure the smoke accumulation in relation to the operation of the smoke detector. A second smoke meter was hung at the 5 foot (1.5 m) level adjacent to the bed and recorded the smoke level to which the occupant might have been exposed upon getting out of bed. Following each test, an estimate of the size of the damaged area was made. No measurements were made of the toxic gas concentrations.

4.3 Test Fires

A total of nine tests were conducted in the course of this series. Five fires were started using a smoldering ignition source and four using an open flame ignition source. The smoldering ignition source consisted of a king-sized non-filtered cigarette placed on the bottom sheet and covered with the top sheet. The open flame ignition source was a non-failsafe cigarette lighter filled with liquid fuel. In order to simulate an open flame ignition the flaming lighter was dropped from a height of 2 feet (0.61 m) onto crumpled sheets. In all test fires the point of ignition was located in the center of the thermocouple array described above. In all cases, the room door was closed during the test. Ventilation was supplied by natural convection through the view port and two 240 square inch (1548 cm^2) openings in the floor.

All test fires were set in bedding materials. The mattresses were of the single bed size, with cotton ticking and padding. All of the mattresses were previously used and were obtained from the Veterans Administration Hospital in Washington, D.C. These mattresses did not meet the present flammability criteria [7] and have chosen to represent

the worst case conditions.

For each fire the beds were made up using two sheets each composed of 50% cotton and 50% polyester fiber material. This fiber blend was used to represent typical materials. Presently, only one manufacturer produces 100% cotton sheets and it is expected that this type sheet will be discontinued in the near future. Two bed configurations were used in these tests (see Figure 5). For tests using a smoldering ignition source the mattress was laid flat on the bed frame. For those tests using an open flame ignition source the mattress was bent at an angle of 45° from the horizontal with the ignition area being at the crease of the sheets.(1) The results of the Level 1 system tests are shown in Table 1.

In addition to the five tests conducted on the detector actuated sprinkler system, three tests were conducted to evaluate the relative response times of both detectors to smoldering and flaming fires. Both the photoelectric and ion-chamber detectors were exposed to the same fire. The time of operation and the smoke level at the ceiling and 5 feet (1.5 m) above the floor were recorded for each test. Since it was desired that both detectors operate prior to extinction, each of these fires was extinguished manually following operation of the second detector. The results of these tests are shown in Table II.

Finally, one test was run to compare the smoke level and room temperatures at the operating point of five currently available automatic sprinkler heads and one prototype. Both 135 °F (56.7 °C) and 165 °F (73.2 °C) heads were used. For this test, as in the test of the detectors alone, the suppression system was rendered inoperative in order that the relative times of sprinkler head operation might be obtained. The results of this test are shown in Table III.

5. DISCUSSION OF RESULTS

5.1 Detector Actuated Sprinkler

The results of the five tests of the detector actuated sprinkler system indicate that the system as tested can detect and respond rapidly to fires from both smoldering and flaming ignition sources. The maximum damage sustained from a smoldering ignition source was 314 square inches (2026 cm^2). This test was conducted with an ion chamber detector and lasted for 1 hour 13 minutes 55 seconds. At that time the smoke level in the test room was considered marginally tenable.(2) Smoke concentration at the 5 foot (1.5 m) level in this test was 7.8 percent per foot (0.11 ODm^{-1}) and 11.3 percent per foot (0.16 ODm^{-1}) at the ceiling. For fires initiated with an open flame ignition source the largest area damaged was 200 square inches (1290 cm^2). This fire was detected and extinguished at 1 minute and 45 seconds. Photographs of typical burn damage following actuation of the system are shown in Figures 6 and 7.

(1) This orientation was chosen to simulate the effects of a person sitting in bed or a raised hospital type bed.

(2) Watanabe [8] suggests 9.2 percent per foot (0.13 ODm^{-1} at the ceiling for those persons familiar with their surroundings.

5.2 Multiple Detector Test

The results of the multiple detector tests indicate an advantage of the photoelectric detector over the ionization detector when exposed to smoldering fire. In one test with a smoldering fire, the photoelectric detector was 16 minutes 55 seconds faster. The difference in operating times between the two types of detectors was nearly as large in the case of the flaming ignition source. In the flaming ignition test, the ion-chamber detector responded 8 seconds ahead of the photoelectric detector.

5.3 Automatic Sprinkler Head Test

A test of the operating times of the six sprinkler heads exposed to an open flaming fire with the bed in the 45° configuration showed the fastest operating time to be 2 minutes 30 seconds. This was achieved with the prototype low thermal lag 135 °F (56.7 °C) sprinkler head. The next fastest was a center strut 135°F (56.7 °C) with heat collectors. This head operated in 2 minutes 52 seconds. This was followed by an on-off sprinkler head rated at 165 °F which operated at 3 minutes 1 second. The last head to operate was a glass bulb type in 3 minutes 45 seconds. Although the smoke level both at the ceiling and 5 feet (1.5 m) above the floor were within tolerable limits at the operating point of each of the sprinkler heads, temperatures at the head of the bed were well beyond tolerable limits and it is likely that any person occupying the bed under these conditions would have been severely burned.

The time-temperature curve and smoke development at the ceiling are shown in Figures 8 and 9. It can be noted that had the Level 1 system been operational during this fire, with the smoke detector alarming at an obscuration of 2% per foot (0.085 ODm^{-1}) the fire would have been arrested in approximately 40 seconds (see Figure 9). At that point the temperature in the immediate area of ignition was approximately 900 °F 481.7 °C) while the temperature at the head of the bed was close to 100 °F (37.7 °C). It can also be seen from Figure 8 that at 150 seconds, the operating time of the fastest sprinkler head, the temperature measured at the head of the bed had exceeded 1500 °F (814.7 °C).

6. SUMMARY

As a result of this preliminary investigation, the following tentative conclusions have been reached:

1. The system as tested, although probably not capable of giving complete Level 1 protection, can provide a higher degree of protection than sprinklers alone. In those cases where the fire is initiated by a smoldering ignition source, it is likely that nearly 100% of those persons exposed to such a fire could be saved. The life saving potential of this sytem for fires initiated by flaming ignition sources is much more time-critical, and therefore more difficult to evaluate. Factors such as blanket, sheet, and sleep-wear flammability need to

be evaluated with instrumented mannequins before firm conclusions can be reached. Based on the extent of damaged area it is estimated that perhaps one-third of the victims of fires originating with open flaming ignition might be saved using the system as tested. It should be noted that even those persons saved may suffer severe thermal trauma. Based on the Oregon data previously cited this could result in a combined reduction of approximately 40% in single fatalities from both fire types. It must also be considered that in addition to providing some degree of Level 1 protection this system also provides Level 2 and Level 3 protection. Its use then could result in a decrease in the number of multiple deaths both within and beyond the room of origin.

2. False alarms with smoke detectors are often a problem under ordinary circumstances, but when this detector is connected to a device which automatically releases water into an area occupied by sick or elderly persons, the false alarm problem is greatly magnified. Although little data exist concerning this problem, a British study [9] indicates smoke detectors have a false alarm to real fire ratio of 14 to 1. About 25 percent of these false signals are related to ambient conditions such as smoking, cooking, or other sources of smoke not related to a hostile fire. Although much of the British data comes from non-institutional occupancies, even reduction to a false alarm ratio of 5 to 1 for burning homes would be intolerable. It is not difficult to imagine a false alarm occurring when two patients each having two visitors and all four smoking in the same room.

   Although the use of a photoelectric detector might reduce the false alarm problem, it is difficult to predict the exact degree to which the problem will be alleviated. Even a two-thirds reduction to the published figures from Great Britain may not be sufficient. In the opinion of the author, a maximum false alarm ratio of 1 to 1 would be desirable for detectors used in these systems. Raising the alarm threshold, electronically instituting a predetermined delay in operation, or manual actuation of the sprinkler head following a pre-signal from the smoke detector could reduce the number of false alarms. But any delay in the system would greatly reduce the Level 1 effectiveness for open flame ignition fires.

3. These test results suggest that a photoelectric detector may be the most appropriate triggering device for these systems to be used in nursing homes and care-type occupancies. Although the photoelectric detector was slightly slower to respond to the open flaming fire than the ionization detector, there is an advantage to the use of photoelectric

detectors. A photoelectric detector using an incandescent light source will not be nearly as sensitive as an ion chamber detector to cigarette smoke, since that detector responds best to particles greater than 0.3 micrometres. The ion chamber detector is particularly sensitive to smoke particles in the 0.01 to 0.1 micrometre range. The particle size distribution in cigarette smoke falls largely within this range, thus making the ionization detector more sensitive to this source of false alarm.

4. Automatic sprinklers alone cannot provide Level 1 protection. Sprinkler heads alone, however, can provide Level 2 protection against fires initiating from open flame ignition sources. Sprinklers cannot however, provide adequate Level 2 protection from smoldering fires. Work by Hafer and Yuill [10] indicates that it can take up to nearly 4 hours for a smoldering mattress to produce sufficient heat at the ceiling to operate a sprinkler heat. At this point smoke and toxic gas are at lethal levels.

5. The use of separate smoke detection and sprinkler systems in the same room can provide partial Level 1 protection by detection of smoke from smoldering fires, complete Level 2 and Level 3 protection.

6. Based on present price figures it is estimated that the Level 1 Protection system as tested above would cost between \$300 and \$800 per bed: depending on the system design and whether the system is installed in new construction or is being retro-fitted to an existing building. Such a system fitted to an existing facility with 50 beds could cost \$40,000. One possible approach to cost reduction would be to provide Level 1 protection in only one area of a facility and use that area to house persons who might be considered smoking risks. Reduction in patient risk from open flaming fires may also be achieved through use of bedding and sleepwear made of fabrics which are either treated to achieve fire retardant properties or made from fibers which are inherently fire resistant.

7. TENTATIVE DESIGN CRITERIA

The following tentative design criteria are based on the results of this test series and reflect the performance of the system as tested:

1. To provide the level of protection described in these tests any smoke detector chosen to actuate the sprinkler system must have good response characteristics to slowly moving smoke. It is suggested that the detector be capable of responding to minimum smoke obscuration level not exceeding 2% per foot (0.85 ODm^{-1}) at a velocity of 15 feet per minute (7.62 cm sec^{-1}). Although these

performance data are not presently being obtained for detectors in commercial listing and approval procedures, a test method and the test apparatus are being developed at the National Bureau of Standards.

2. Placement of detectors is critical in achieving maximum system effectiveness. Consideration of ambient room air flow patterns is necessary in establishing locations for detectors for minimum response time. Although alternate detector sites were not evaluated in these tests, it is suggested that the detector should be placed on the ceiling above or between beds on a line approximately 3 feet (0.9 m) from the head of the bed. This places the detector over or adjacent to the part of bed where flaming ignition is likely to provide the most serious exposure to the occupant.

   Spacing of detectors should not exceed 10 feet. Increased coverage may cause delays in detection with a resulting reduction in system effectiveness with open flaming fires.

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TABLE I

RESULTS OF LEVEL 1 SYSTEM TESTS
INVOLVING IGNITION AND AUTOMATIC SUPPRESSION OF BEDDING FIRES

Test Number	Detector Type (a)	Ignition Source (b)	Time of Operation (hr:min:sec)	Smoke Level at Operation OB % Ft^{-1} (ODm^{-1})		Temperature at Operation °F (°C)		Maximum Temperature in Bedding °F (°C)	Damage Area in^2 (cm^2)
				Ceiling	5 Feet	Ceiling	5 Feet		
1	PE	S	0:33:48	1.7 (0.02)	0.99 (0.01)	61 (16)	61 (16)	347 (175) (ignition area)	20 (127)
2	IC	S	1:13:55	11.3 (0.16)	7.8 (0.11)	84 (29)	66 (19)	702 (372) (ignition area)	314 (2026)
3(d)	PE	S	0:22:46	1.4 (0.02)	0.29 (0.002)	63 (17)	57 (14)	709 (376) (ignition area)	20 (127)
4	PE	F	0:1:45	4.3 (0.06)	0 (0)	(c)	(c)	(c)	200 (1290)
5	IC	F	0:0:36	(e)	(e)	(e)	(e)	(e)	80 (516)

(a) PE = Photoelectric
IC = Ion Chamber

(b) S = Smoldering (cigarette)
F = Flaming (lighter)

(c) No temperatures due to equipment failure

(d) Prototype thermal actuator not presently on the market

(e) No temperature or smoke data due to equipment failure

TABLE II

DETECTOR OPERATION
Results of Multiple Detector Tests

Test Fire	Photoelectric			Ion Chamber		
		Obscuration at Alarm % Ft^{-1} (ODm^{-1})			Obscuration at Alarm % Ft^{-1} (ODm^{-1})	
	Time (min:sec)	Ceiling	5 Feet	Time (min:sec)	Ceiling	5 Feet
Cigarette on mattress filling (cotton padding)	12:10	2.0 (0.028)	.8 (0.011)	16:00	3.5 (0.049)	1.3 (0.018)
Cigarette folded within sheets	28:35	1.0 (0.014)	.6 (0.008)	45:30	9.0 (0.128)	4.1 (0.058)
Flaming lighter dropped	0:42	3.8 (0.054)	0 (0)	0:34	1.5 (0.021)	0 (0)

TABLE III

RESULTS OF SPRINKLER OPERATION TEST WITH AN OPEN FLAME IGNITION SOURCE

Head[a] Number	Rating °F (°C)	Operation Time (min:sec)	Temperature at Operation °F (°C) Ceiling	5 Feet	Smoke Level at Operation OB % Ft^{-1} (ODm^{-1}) Ceiling	5 Feet	Temperature at Head of Bed °F (°C)
1	135 (56.7)	2:30	161 (72)	79 (37)	4.8 (0.07)	3.2 (0.05)	1089 (587)
2	135 (56.7)	2:52	252 (122)	136 (58)	5.8 (0.08)	5.2 (0.07)	1206 (652)
3	165 (73.2)	3:01	259 (126)	147 (64)	6.1 (0.09)	4.5 (0.06)	1263 (684)
4	135 (56.7)	3:18	261 (127)	169 (76)	6.7 (0.10)	4.0 (0.057)	824 (440)
5	165 (73.2)	3:14	259 (126)	163 (73)	6.1 (0.09)	3.9 (0.055)	900 (482)
6	135 (56.7)	3:45	239 (115)	174 (79)	8.3 (0.12)	4.5 (0.06)	606 (319)

(a)
1 = Prototype low thermal lag sprinkler
2 = Center strut with heat collectors
3 = On-off sprinkler
4 = Center strut
5 = Old-style 165°F (73.2°C) center strut
6 = Glass bulb

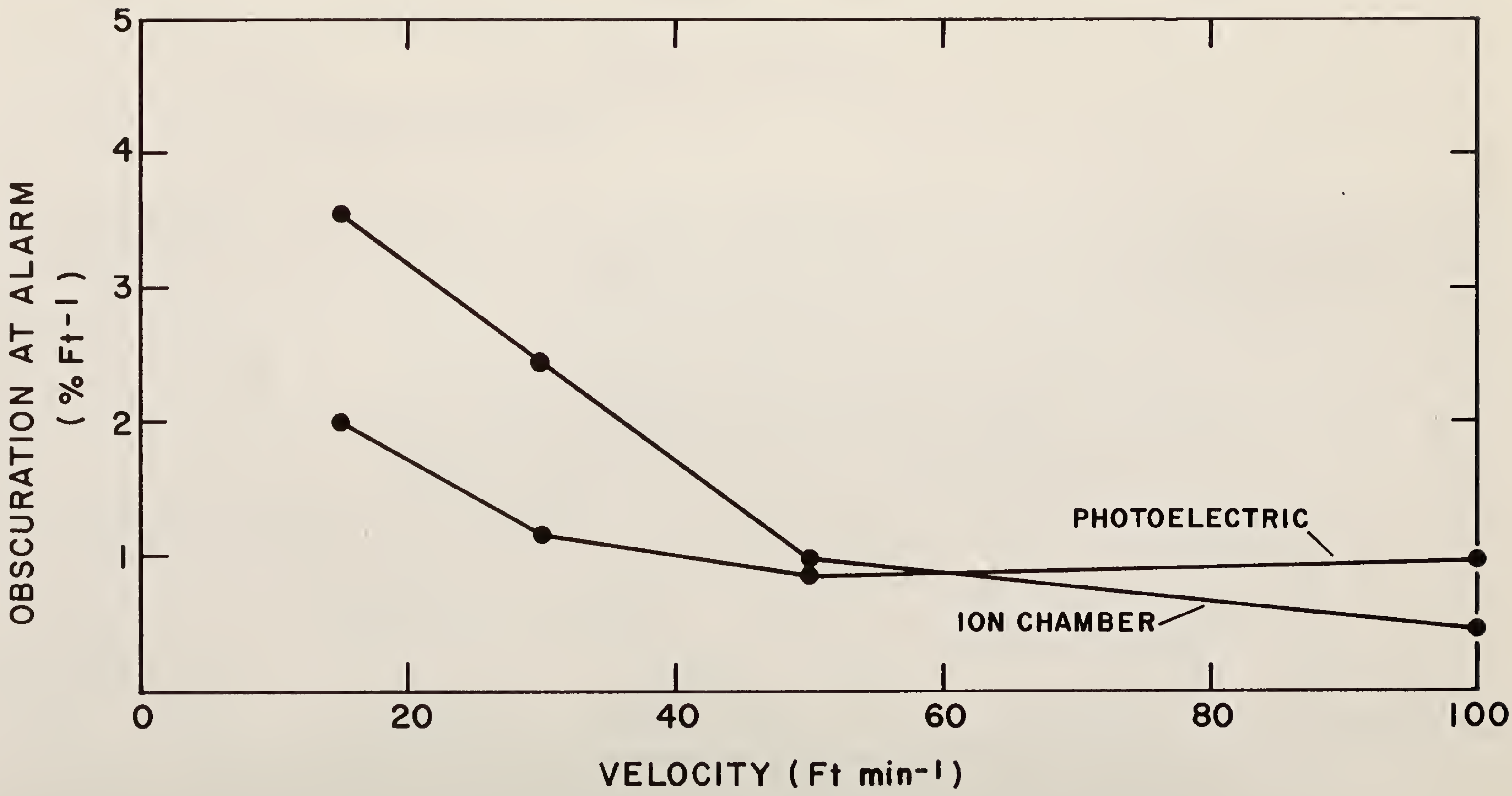


Figure 1. Velocity profiles for test detectors.

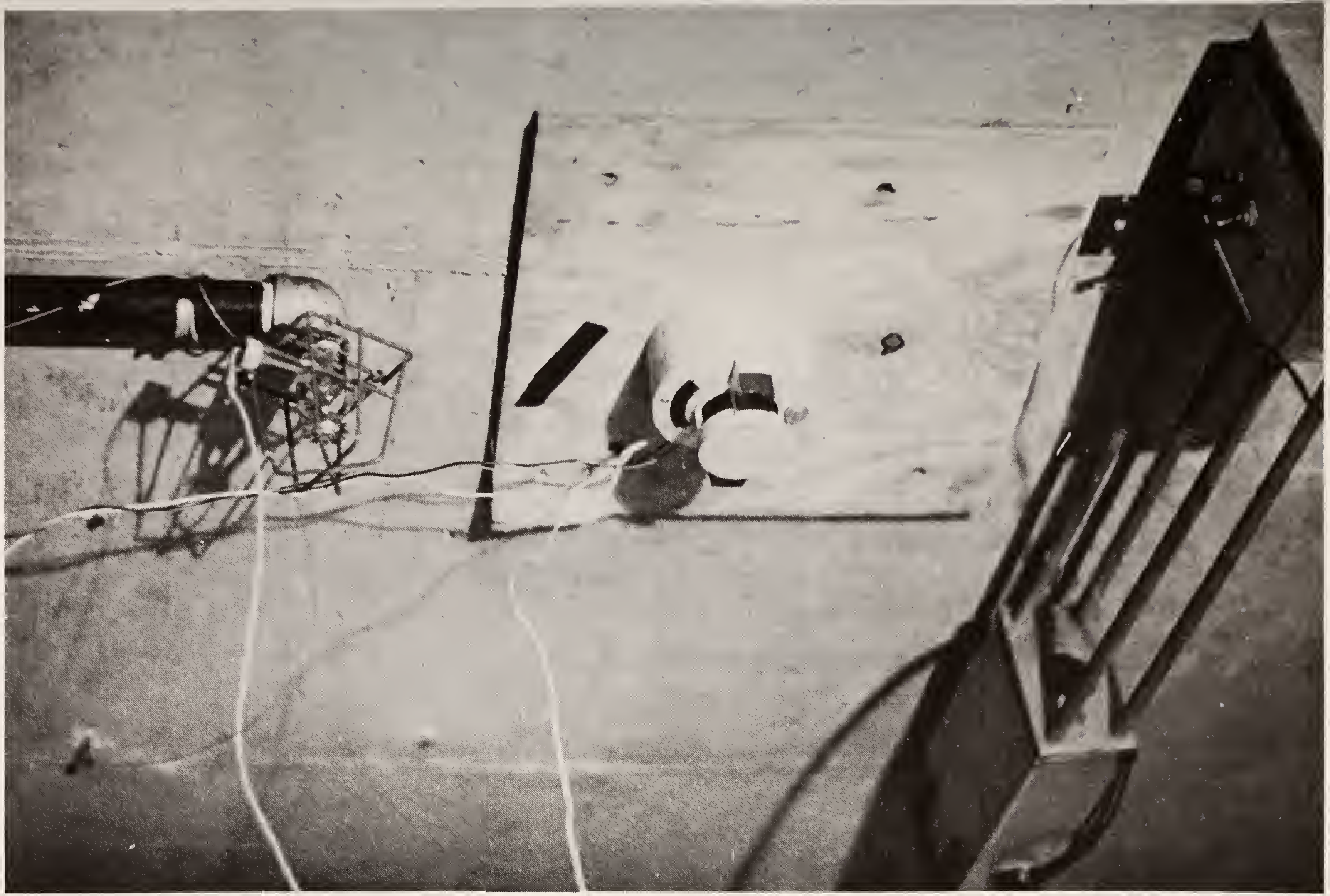


Figure 2. Arrangement of components for experimental level ' system.

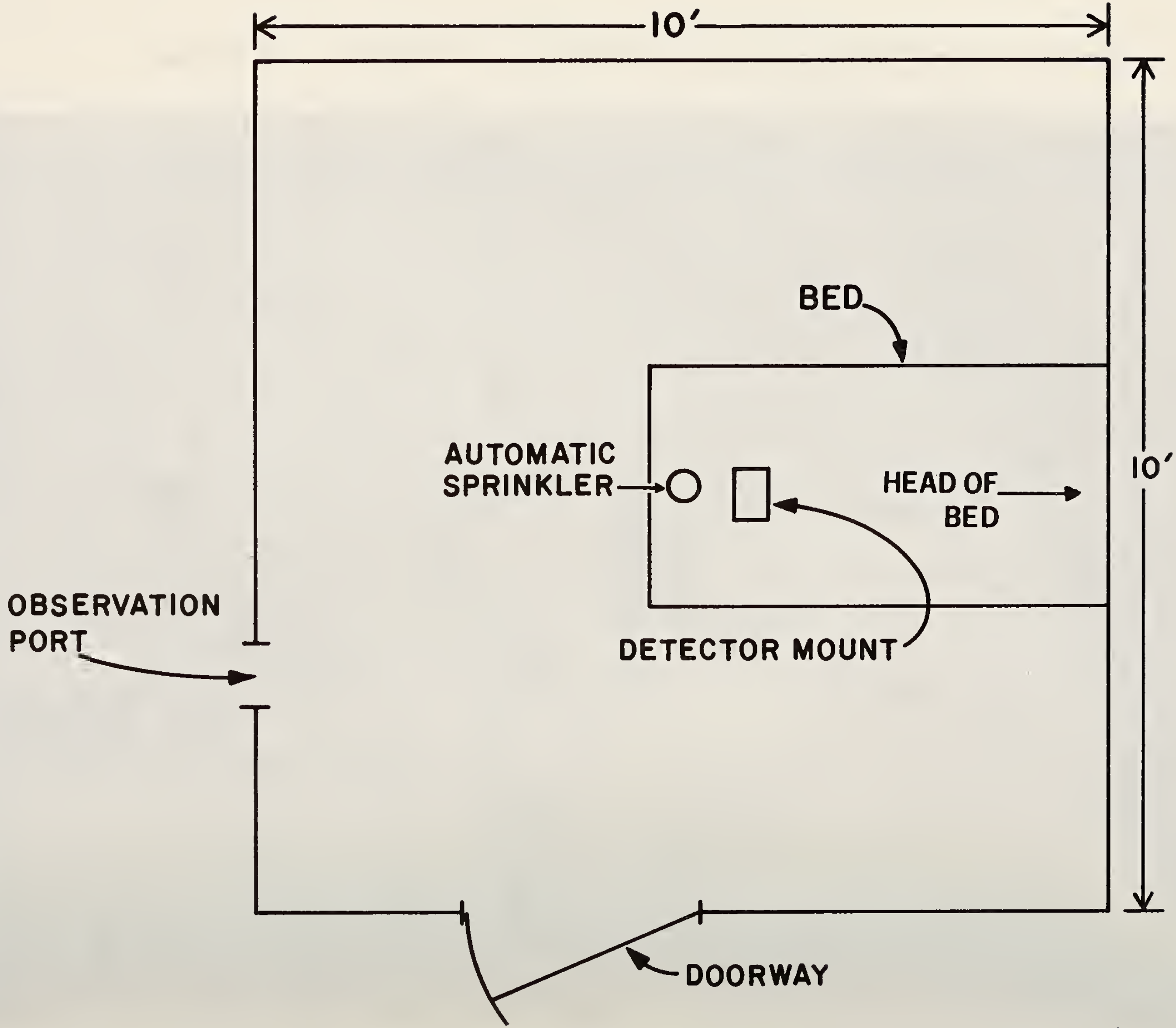


Figure 3. Layout of test room.

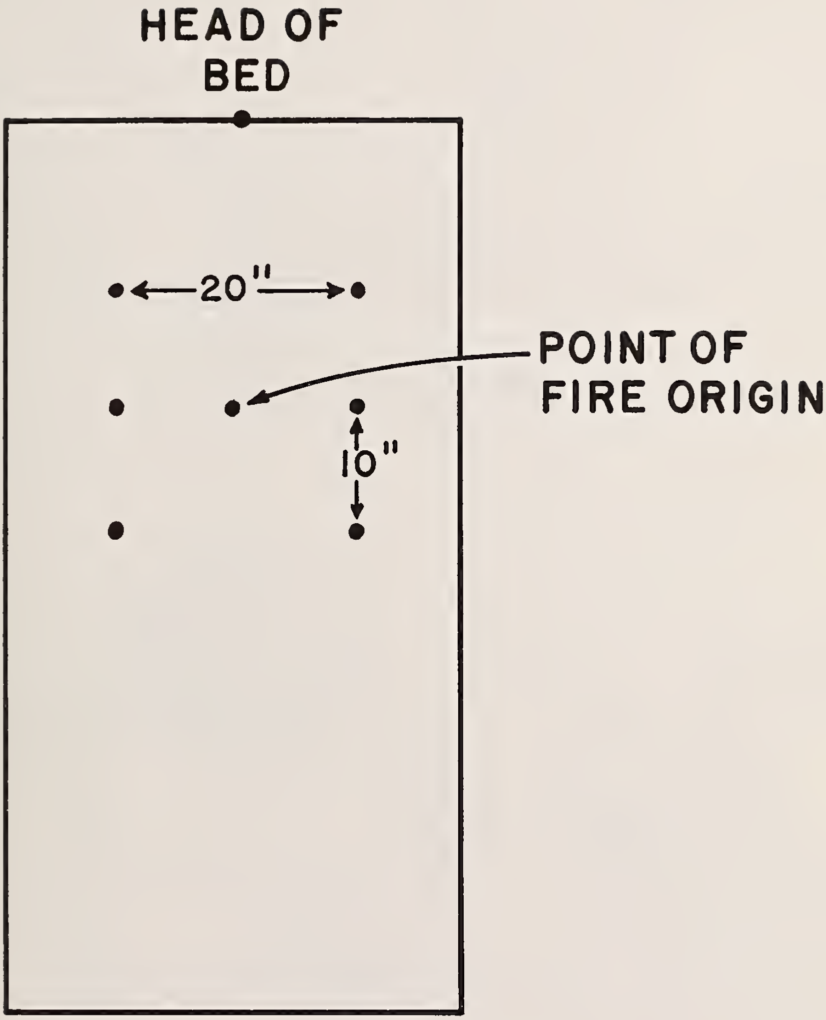
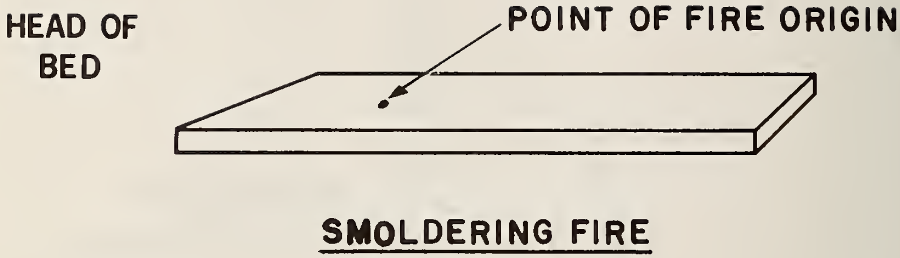


Figure 4. Location of thermocouples on test bed.



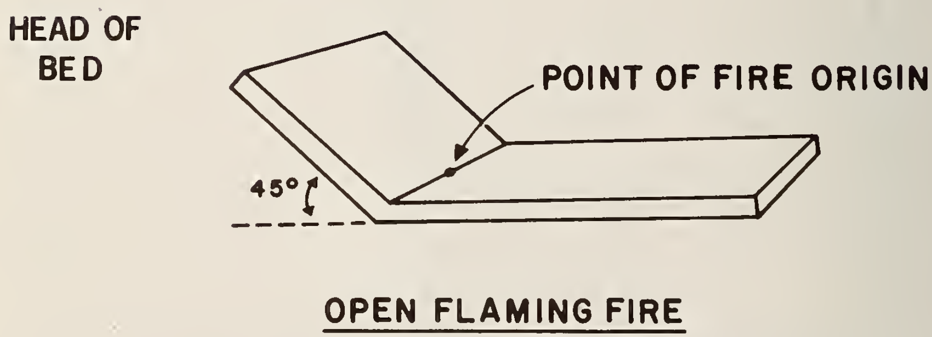


Figure 5. Bed configurations.

Figure 6. Smoldering fire suppressed at 22 minutes 46 seconds.

Figure 7. Flaming fire suppressed at 1 minute 45 seconds.

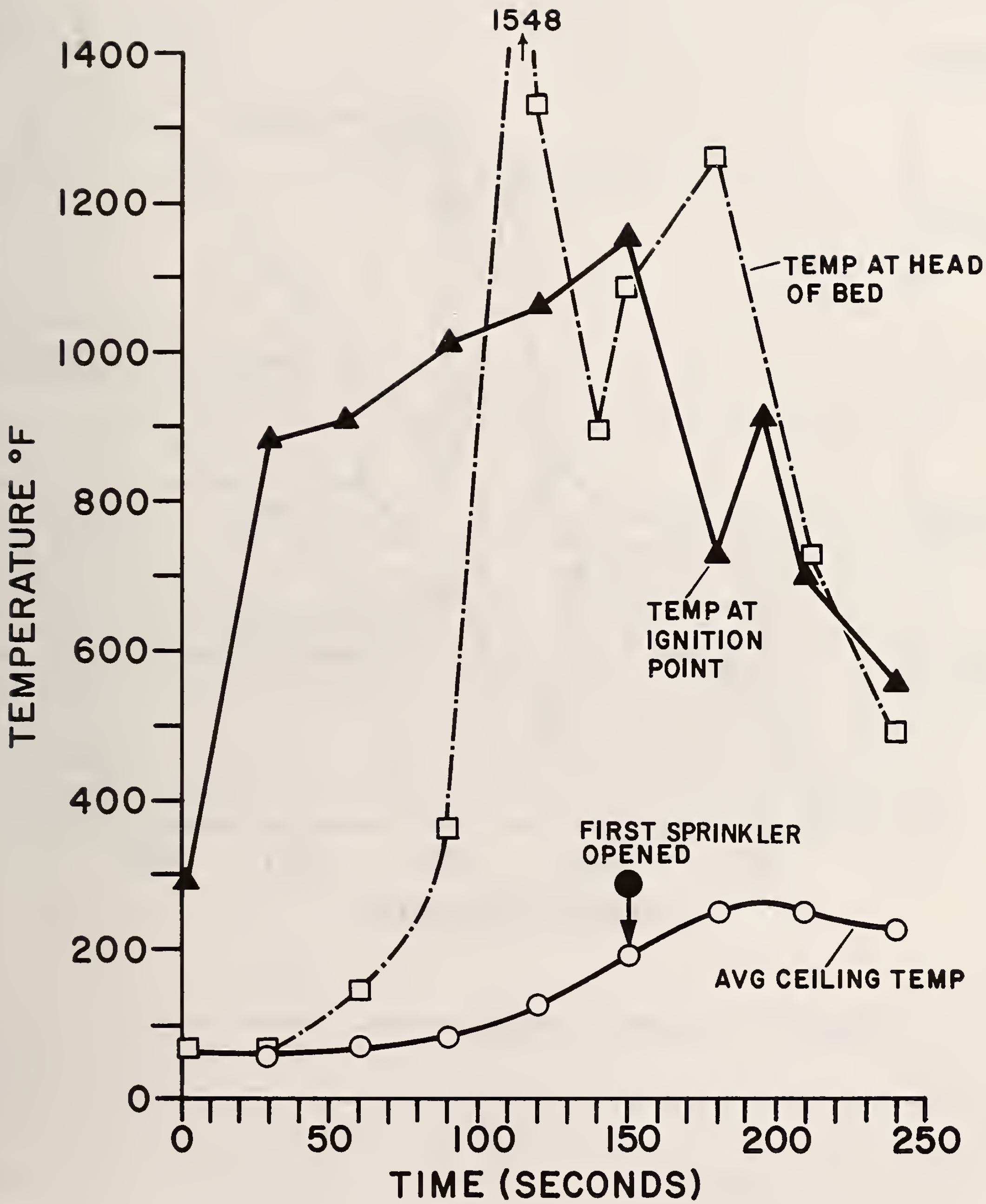


Figure 8. Sprinkler operation test: temperature levels.

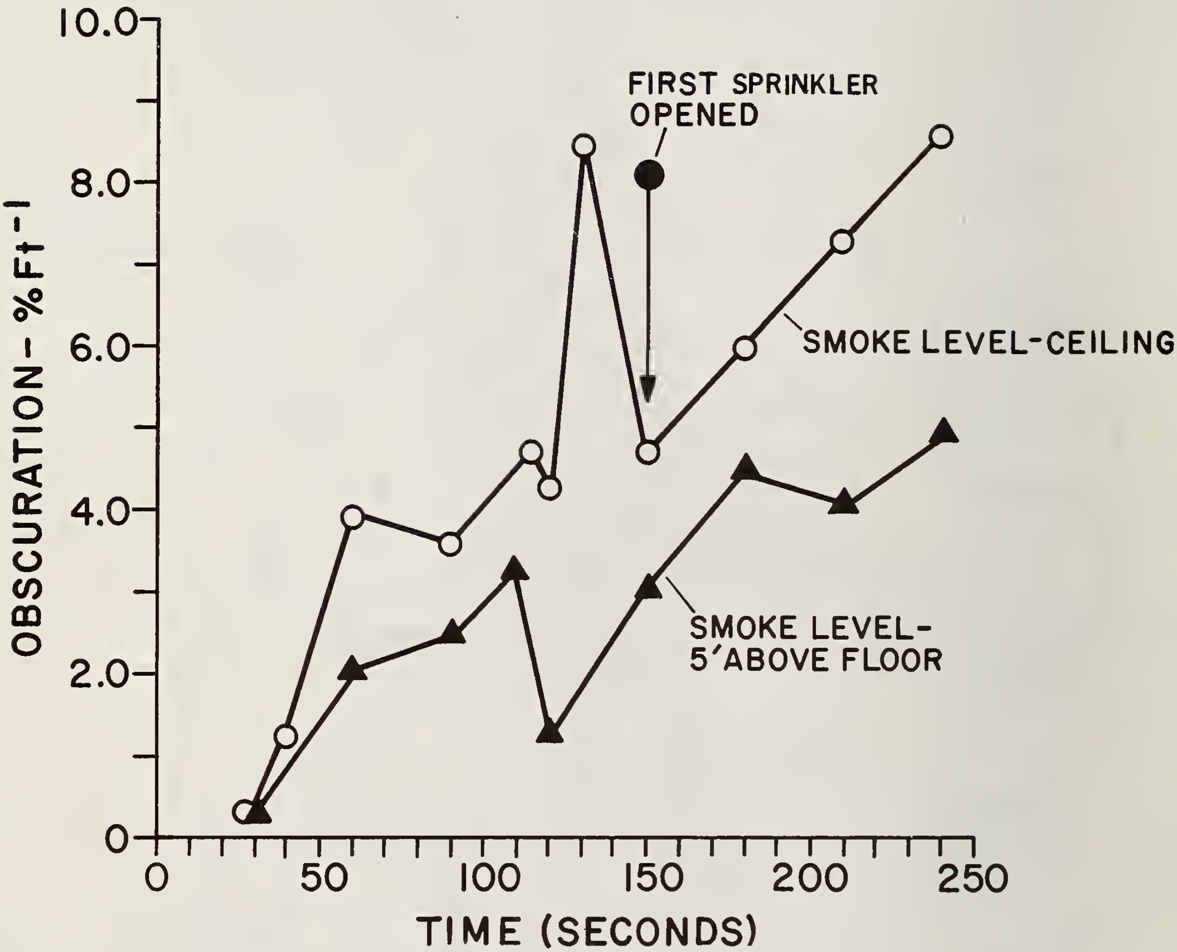


Figure 9. Sprinkler operation test: smoke levels.

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

An investigation was conducted to evaluate the capabilities of a detector actuated automatic sprinkler system to protect individuals who are intimately associated with the first materials ignited such as bedding materials. Tests were conducted in a simulated nursing home bedroom. System response was evaluated for both smoldering and open flaming ignition sources. It was determined that barring electrical or mechanical failure the system could be nearly 100 percent effective with smoldering fires. The effectiveness with open flaming fires was difficult to evaluate. Although these fires were extinguished with minimum damage in times as short as 36 seconds the possible effects of flammable blankets and sleepwear were not tested. It was estimated that perhaps one third of the potential victims of open flaming fires might be saved. Although these tests were limited in scope, some tentative design criteria for detector actuated sprinkler systems are presented and possible alternatives offered.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Bedding fires; design criteria; detector actuated automatic sprinklers; detectors; levels of protection; life safety; sprinklers.

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